The potassium status of 8 Fijian soils representing those commonly used for sugarcane production was evaluated. Samples were taken from fields where continuous cane production has been practiced for 20 to 75 years and from nearby fields where cane had been grown in rotation and sites had been in a fallow state for five to eight years prior to sampling. The K status of soils, as measured by levels of exchangeable K and soil solution K, was low on the majority of sites. Five of the sites were situated on strongly weathered oxidic soils where total K content was low and K retention capacity (net soil negative charge) also tended to be low. Two less weathered soils contained significant amounts of 2:1 expandable layer silicate minerals and had a much higher total K and non-exchangeable K content than the other 5 strongly weathered soils. However, on both of the less weathered soils intensive cultivation resulted in a decrease in non-exchangeable as well as exchangeable K in comparison with fallowed sites. This indicates that net removal of K was occurring at the intensively cultivated sites. It was concluded that the K status of the study soils was low and in view of the high K requirement of sugarcane more attention needs to be paid to K fertilizer rates and practices in the study area.

Key words: Sugarcane, Fiji, potassium, soils.

INTRODUCTION

The sugar producing areas of Fiji are located in the western half of the island of Viti Levu and in the northeast of Vanua Levu. These areas encompass a wide spectrum of soils which can differ greatly in properties according to parent material from which they have been formed and the environmental conditions under which they have been developed (Yang and Chen). As a consequence, fertilizer recommendations vary depending upon the major soil group in which the sugarcane is being grown (Yang and Chen). In addition, previous cropping history of the field is likely to greatly influence soil fertility.
Fijian soils are generally acid, severely P-deficient and several other nutrients (S, K, Mg and Si) tend to be present in the soil solution in very low concentrations (Curtin et al²). Although Yang and Chen¹ concluded from 10 years of field trials that N was the most limiting nutrient for sugarcane production in Fiji followed by P and K deficiencies of K have been observed in Fijian sugarcane fields. In a preliminary study of the soil solution composition of the sugarcane growing soils of Fiji Gawandar and Naidu‘ concluded that all soils studied appeared to be K-deficient. This is of particular concern because it is well known that compared with most other agricultural crops, sugarcane has a very high demand for K (Husz³). Total quantities of K removed by a 100 t ha⁻¹ cane crop have been reported to range from 125 to 220 kg K ha⁻¹ (Husz⁴, Bishop⁵).

In this study, the effects of long-term sugarcane production on soil K status is determined by comparing the total, exchangeable, non-exchangeable and soil solution K status of intensively cultivated fields that had been under continuous cultivation for 35 to 75 years with that of fields where cane had been grown in rotation and the ground had been left fallow for five to eight years prior to sampling.

**MATERIALS AND METHODS**

Surface (0-200 mm) samples of soil were collected from sites on the Fijian islands of Viti Levu and Vanua Levu (Figure 1). Paired samples were collected from (a) sites with a long history of continuous sugarcane cultivation (i.e. 20 to 75 years) which were designated as 'cultivated' and (b) sites where sugarcane had been grown in rotation and fields had been in a fallow state (covered with grassy vegetation) for five to eight years prior to sampling (designation as "fallow"). Soils were air-dried and sieved (< 2 mm) prior to chemical analysis. The classification, mineralogy and some chemical properties of the soils are presented in Table 1.

Soil pH was determined in 1:2.5 soil: 0.01 M CaCl₂ suspension following equilibration for 16 hr. Oxidizable organic carbon in soils was estimated by the dichromate method (Walkley and Black⁶). The distribution of +ve and -ve charges on soil colloids at natural soil pH was estimated by ion adsorption (Naidu et al⁷). Total K content of the soil samples was determined by X-ray fluorescence (Norrish and Hutton⁸). Potassium in external soil solution was determined in a saturation paste extract following overnight equilibration of soils in distilled-deionized water. Exchangeable K was extracted from soil samples by shaking 10 g soils with 25 cm³ of ammonium acetate for 2 hrs. Non-exchangeable K was extracted with boiling M HNO₃ for 1 hr (Pratt⁹). Non-exchangeable K values presented represent the difference between the HNO₃-extractable K and the exchangeable K. The 450°C extractable K was obtained by ashing soils at 450°C in a muffle furnace and then extracting the residue with ammonium acetate (Sharpley and Smith¹⁰). Values of 450°C-K
determined this way are presented in...
TABLE 1. Some properties of the study soils.

<table>
<thead>
<tr>
<th>Location</th>
<th>Soil</th>
<th>USDA Classification</th>
<th>Mineralogy of clay fraction</th>
<th>pH (0.01 CaCl₂)</th>
<th>Organic C (%)</th>
<th>Charge (mmol kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Negative</td>
</tr>
<tr>
<td>Batiri fallow cultivated</td>
<td>Lithic Ustopept</td>
<td>K, Gib, Geoth</td>
<td>4.5</td>
<td>1.42</td>
<td>49.9</td>
<td>42.0</td>
</tr>
<tr>
<td>Drasi fallow cultivated</td>
<td>Oxic Haplustoll</td>
<td>K, Gib, Geoth</td>
<td>4.4</td>
<td>1.90</td>
<td>38.4</td>
<td>15.4</td>
</tr>
<tr>
<td>Legalega fallow cultivated</td>
<td>Typic Eutruxtol</td>
<td>K, Gib, Geoth</td>
<td>4.2</td>
<td>1.01</td>
<td>32.2</td>
<td>9.2</td>
</tr>
<tr>
<td>Lalakoro fallow cultivated</td>
<td>Ustoxic Pellustoll</td>
<td>K, Gib, Geoth</td>
<td>4.2</td>
<td>4.50</td>
<td>104.0</td>
<td>15.1</td>
</tr>
<tr>
<td>Naduri fallow cultivated</td>
<td>Typic Acruxtol</td>
<td>S, K, Gib, Geoth</td>
<td>4.4</td>
<td>3.40</td>
<td>59.0</td>
<td>14.5</td>
</tr>
<tr>
<td>Nawaicoba fallow cultivated</td>
<td>Typic Pellustoll</td>
<td>S, K</td>
<td>6.2</td>
<td>2.32</td>
<td>439.0</td>
<td>4.4</td>
</tr>
<tr>
<td>Sigatoka fallow cultivated</td>
<td>Typic Hapludoll</td>
<td>S, K</td>
<td>6.0</td>
<td>1.86</td>
<td>574.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Seqaqa fallow cultivated</td>
<td>Tropheptic Haplustoll</td>
<td>K, Gib, Geoth</td>
<td>4.0</td>
<td>2.32</td>
<td>163.0</td>
<td>17.3</td>
</tr>
</tbody>
</table>

*S = smectite, K = Kaolinite, Gib = Gibbsite, Geoth = Geothite and Q = quartz.

FIGURE 1. Map of Fiji Islands showing location of sites.
presented represent the difference between the K extracted following heating to 450°C and that extracted with boiling HNO₃. Potassium in all extracts was determined by atomic absorption spectrophotometry.

For the determination of the effect of long-term sugarcane cultivation on sorption of K, replicate soil samples (2 g) were weighed into a series of polypropylene centrifuge tubes and 20 cm³ of background electrolyte, 0.002M CaCl₂ containing different amounts (0 to 1,000µg K) of K as KCl were added. The samples were then equilibrated on an end-over-end shaker for 16 hrs and centrifuged. Following centrifugation, the supernatants were analysed for K.

RESULTS AND DISCUSSION

Total potassium

Two broad groups were recognized within the 8 study soils. The Batiri, Drasa, Legalega, Lalako, Nadiri and Seqqa soils represented acidic, strongly weathered oxidic soils whilst Nawaicoba and Sigatoka were more recent, less weathered soils which had a considerably higher pH than the others (Table 1). Total K content of strongly weathered soils was low ranging from < 2 mmol kg⁻¹ for fallow Batiri soil to 13.3 mmol kg⁻¹ for cultivated Legalega soil (Table 2). In contrast, the less weathered Nawaicoba and Sigatoka soils had a total K content in excess of 90 mmol kg⁻¹.

Bear et al.¹¹ reported that for 20 soil samples from New Jersey, average total K content was > 450 mmol kg⁻¹ soil and in a more recent study Sharpley and Smith¹⁰ showed that the total K contents for 8 soils from major agricultural areas of the United States ranged from 20 mmol kg⁻¹ to > 400 mmol kg⁻¹. It is therefore evident that soils in this study, except for Nawaicoba and Sigatoka have a very low total K content.

The effects of intensive cultivation on total K content of soils was variable with increases being recorded in three cases and decreases in the other five cases. Changes in total K content will be related to the total inputs and losses of K that have occurred during agricultural activity. Where net K inputs have occurred (i.e. fertilizer inputs have exceeded losses through crop removal and/or leaching) there will be a gain of soil K. Where losses have exceeded fertilizer inputs a decrease in K content due to intensive cultivation will have occurred.

Non-exchangeable potassium

2:1 type clay minerals such as hydrous micas and illite contain K which is part of their mineral structure. The K is held strongly within the interlays of these minerals and
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An additional method of measurement was also used. Soil was heated to 450°C. This causes exfoliation of micaceous soil materials exposing K to the solution which was formerly inaccessible in contracted interlayers (Smith and Scott).

In the majority of soils, levels of non-exchangeable K were low often being less than 10 mmol K kg⁻¹ (Table 2). The notable exceptions were the Nawaicoba and Sigatoka soils both of which contained amounts of NO₃-K and 450°C C-K. Analysis of the mineralogy of the clay fraction of these soils (Table 1) showed that both the recent Nigrescent Nawaicoba soil and the recent alluvial Sigatoka soil contained significant amounts of the 2:1 mineral smectite.
Such soils are characteristically known to have a high K status (Yang and Chen). Nonetheless, it is notable that intense cultivation had significantly reduced the level of this reserve K in both soils suggesting that there has been a net loss of K from both sites under intense cultivation.

Exchangeable K

Concentrations of exchangeable K varied greatly between soils and between sites on the same soil (Table 2). On the cultivated sites exchangeable K levels ranged from 0.44 to 2.2 mmol kg⁻¹ with a mean value of 1.34 mmol kg⁻¹. These values are low compared with those normally recommended for sugarcane-growing soils. Orlando Filho, for example, observed that critical exchangeable K levels for sugarcane are quoted as 2.6 for Hawaii, 3.2 for Barbados and 2.0 mmol kg⁻¹ for Australia. For South African soils, Meyer and Wood suggest a critical exchangeable K level of 2.9 for light and medium textured soils and 5.8 mmol kg⁻¹ for heavy textured soils. It therefore seems likely that K was deficient in most of the sampled fields, particularly those under intense cultivation. In an overview of the soil resource of Fiji, Twyford and Wright suggested that for an average cane yield of 112 t ha⁻¹, critical exchangeable K levels ranged from 6.4 - 7.7 mmol kg⁻¹.

Intensively cultivated sites had lower exchangeable K levels than fallow sites for five of the soils but the reverse was the case for the Batiri, Drasa and Legalega soils. As noted previously, these changes will be related to the relative size of inputs (mainly fertilizer K) versus losses (mainly crop removal and leaching). In order to maintain soil K status the amount of K removed in the harvested crop (i.e. 125-220 kg K ha⁻¹ per 100 t ha⁻¹ cane crop) must be applied annually. In addition, in tropical soils K leaching can be a problem so that substantially higher dressings of K may need to be applied in order to maintain soil K status. The Batiri, Drasa, Legalega, Lalakoro and Naduri soils all have a relatively low net negative charge (i.e. < 90 mmol kg⁻¹) and therefore will tend to have low capacity to retain K.

A modifying factor is the amount of reserve K present in non-exchangeable form since, as already noted, this is released to exchangeable form as exchangeable levels fall. Thus the K fertilizer recommendation for the smectitic Nawaicoba and Sigatoka soils (50-150 kg K ha⁻¹) is lower than that for the other study soils (e.g., 250 kg K ha⁻¹) (Yang and Chen). It is however worth noting that in these smectitic soils that exchangeable as well as non-exchangeable K is being removed at a greater rate than it can be replenished from non-exchangeable forms. Fertilizer K rates at these sites need to be raised. A complicating factor may well be that some added fertilizer K could be fixed into non-exchangeable form on these essentially K-deficient smectitic soils.
Soil solution potassium

Soil solution K gives an indication of the K intensity factor (i.e. K that is immediately available for plant uptake). Concentrations of K in soil solution ranged from 0.06 mmol to 1.50 mmol with a mean value of 0.31 mmol for intensively cultivated soils. Such values are low compared to those of solution K concentrations of 0.2 or 10 mmol with a mean value of 0.7 mmol reported for subtropical and tropical soils by Fried and Shapirou.

In view of the low levels of exchangeable K present in the study soils and the fact that soil solution K is in equilibrium with exchangeable K, low concentrations of soil solution K were not unexpected. As expected, soil solution K showed similar broad trends to those of exchangeable K. That is, intensively cultivated sites had higher levels of soil solution K than undisturbed sites for the Batiri, Drasa and Legalega soils but the reverse was true for the remaining five soils.

Potassium sorption

The soils differed markedly in their ability to sorb K. In general, sorption increased in the order Legalega < Drasa < Naduri < Lalakoro < Batiri < Seqaqa < Sigatoka < Nawaicoba (Figure 2). These differences were most likely due to the large variations in the net negative charge and in the nature and amounts of layer silicate minerals present in the various soils. For instance, the high sorption observed in the Nawaicoba and Sigatoka soils was most likely due to their high net negative charge and the presence of significant amounts of expanding 2:1 smectite minerals. The active constituent in the Seqaqa soil is likely to have been the large net negative charge (Table 1) associated with that soil.

Intensive cultivation markedly decreased K sorption in the Batiri, Drasa and Legalega soils (Figure 2). This is to be expected since these are the same soils where intensive cultivation resulted in a significant buildup of exchangeable K. For the Lalakoro, Naduri, Sigatoka and Seqaqa soils where exchangeable K was decreased by intensive cultivation, the K sorption capacity was correspondingly increased. For the Sigatoka soil the effect of intensive cropping in increasing K sorption was extremely marked. It is notable however that for this soil there was also an extremely marked decrease in exchangeable K due to intensive cropping. For Nawaicoba soil, K sorption was virtually unaffected by cropping history. As already noted, this soil had the greatest K sorption capacity and as a consequence crop history apparently had only a small effect.
FIGURE 2. Potassium sorption curves for the study soils.

Equilibrium K concentration (mmol dm⁻²)

Quantity of K sorbed (mmol Kg⁻¹)
CONCLUSIONS

The majority of soils were strongly weathered and had a low content of total, non-exchangeable, exchangeable and soil solution K. These soils also tended to have a high net negative charge and therefore are likely to have a weak ability to retain K against leaching. Rates and timing of K fertilizer will therefore be important for these soils. Two less weathered soils had a much higher content of total and non-exchangeable K than the others. These soils also had a reasonable high net negative charge and therefore a reasonably high capacity to retain K. Thus, fertilizer K rates required for adequate cane growth in these soils are likely to be less than those for the strongly weathered soils. Nonetheless, the intensively cultivated sites of these two less weathered soils had lower levels of both non-exchangeable and exchangeable K than their fallow counterparts suggesting that a net loss of K from sites (presumably mainly through crop removal) was occurring.

Overall, the K status of soils was low. Since the K requirement of sugarcane is characteristically high and large amounts of K are removed in the harvested crop, K fertilizer practices need to be scrutinized carefully in the study area. Indeed, on many Fijian soils visual symptoms of K deficiency in sugarcane have been noted and this has been confirmed by plant tissue analysis.

REFERENCES


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LE NIVEAU POTASSIQUE DE CERTAINES TERRES A CANNES AU FIDJI

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RESUME

Le niveau de K fut évalué dans 8 sols représentatifs des terres sous cannes à Fidji. Des échantillons furent prélevés de champs ayant été plantés en canne pendant 20-75 ans, ou cultivés en rotation ou en jachère pendant 5 à 8 ans auparavant. Dans la plupart des sites, les niveaux de K échangeable ou de K en solution étaient faibles. Le K total...
au de K*changeable et non-Cchangeable dans les deux sols moins une perte nette en K. La conclusion est que le niveau de K dans les sols étudiés étant faible et compte tenu des besoins élevés de la canne une attention particulière devrait être accordée à la fertilisation potassique dans ces sites.

Mots clefs: Canne à sucre, Fiji, potasse, sols.

NEROS DE FIJI

RESUMEN

Se evaluó el nivel potásico de 8 suelos caneros en Fiji, tomándose muestras de aquellos dedicados al cultivo de la cana de azúcar durante los últimos 20 a 75 años, y otros donde la caña se había rotado o la tierra había descansado durante los últimos 5 a 8 años previos al muestreo. El potasio evaluado mediante niveles de K intercambiable y K en solución edáfica, era bajo en la mayoría de los suelos. Cinco de los lugares muestreados estaban situados oxidados muy interperizados donde el contenido de K era bajo y la capacidad de retención de K también. Dos suelos menos interperizados contenían cantidades significativas de 2:1 de capas expansibles silíceas, y tenían un contenido de K y de K no-intercambiable mucho más alto que los otros 5 suelos interperizados. Sin embargo, en 2 de los suelos menos interperizados, el cultivo intensivo había disminuido el K no-intercambiable y el K total en comparación con aquellos suelos en descanso. Todo esto indica que la remoción neta de K estaba sucediendo en los suelos con un cultivo intensivo. Se llegó a la conclusión que el nivel potásico de los suelos en estudio era bajo; y debido a los altos requerimientos de K por la caña de azúcar se le debe de prestar más atención a los fertilizantes potásicos, tanto dosis y prácticas de aplicación en el área estudiada.

Palabras claves: Caña de azúcar, Fiji, potasio, suelos.